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Under this grant we have demonstrated that AEOS can be an important new observatory using all-sky imagers and a giant lidar as tools for middle atmospheric studies. Cornell University has invested in the all-sky imager, which has yielded valuable contributions to aeronomy (a total of 5 publications thus far). Three Cornell students have already visited the Maui site, taking airglow data and testing the ability to operate the camera remotely, and several images have been published from that work. In addition, we have designed and carried out a unique set of experiments using the sister facility to the Maui Observatory: the Starfire Optical Range. Working with other upper atmospheric researchers, we have re-opened research into one of nature's most intriguing and least understood phenomena: long-lasting chemiluminescent meteor trails. This experience will be invaluable as the Maui-MLT initiative continues.

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# A Proposal to Establish a Preliminary AOES Element on Maui for Determining the Source of Wave Disturbances in the Mesosphere

P.I.: Michael C. Kelley, Cornell University

**Final Report: F49620-98-1-0339**

## Executive Summary

Under this grant we have demonstrated that AEOS* can be an important new observatory using all-sky imagers and a giant lidar as tools for middle atmospheric studies. Cornell University has invested in the all-sky imager, which has yielded valuable contributions to aeronomy (a total of 5 publications thus far). Three Cornell students have already visited the Maui site, taking airglow data and testing the ability to operate the camera remotely, and several images have been published from that work. In addition, we have designed and carried out a unique set of experiments using the sister facility to the Maui Observatory: the Starfire Optical Range. Working with other upper atmospheric researchers, we have re-opened research into one of nature's most intriguing and least understood phenomena: long-lasting chemiluminescent meteor trails. This experience will be invaluable as the Maui-MLT initiative continues.

*Inadvertently called "AOES" in the original proposal.

*Publications resulting from research supported under this grant:*

Garcia, F.J., M.C. Kelley, J.J. Makela, and C.-S. Huang, Airglow observations of mesoscale low-velocity traveling ionospheric disturbances at midlatitudes, *J. Geophys. Res.*, *105*(A8), 18,407-18,415, 2000.

Garcia, F.J., M.C. Kelley, J.J. Makela, and C.-S. Huang, Mesoscale structure of the midlatitude ionosphere during high geomagnetic activity: Airglow and GPS observations, *J. Geophys. Res.*, *105*(A8), 18,417-18,427, 2000.

Kelley, M.C., J.J. Makela, P.J. Loughmiller, F.J. Garcia, C. Seyler, and E. Dewan, Sharp front observations: Further evidence for mesospheric bores, *J. Geophys. Res.*, to be submitted, 2001.

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Wong, L., *Database Development and Management for the Cornell University Airglow Project*, Master's Thesis, Cornell University, Ithaca, NY, 1998.

Zhou, W., *Unambiguous Two-Dimensional Horizontal Wave Number Spectrum of Ionospheric Airglow Images*, Master's Thesis, Cornell University, Ithaca, NY, 1998.

*Personnel involved in this project:*

Michael C. Kelley, P.I.

Francisco Garcia (Ph.D. awarded)
Craig Kruschwitz, Graduate student (Ph.D)
Jonathan J. Makela, Graduate student (Ph.D)

Lymari Castro (M.Eng. awarded)
Stanley Leong (M.Eng. awarded)
Craig Palmer (M.Eng. awarded)
Levina Wong (M.Eng. awarded)
Wenjin Zhou (M.Eng. awarded)

## Report

All-sky imaging has become a valuable tool in upper atmospheric research, particularly since the advent of digital cameras and innovations in digital signal processing. These technical developments are applicable to the upper atmosphere since many chemical reactions occurring above 80 km result in emissions of photons that easily pass through the atmosphere. Below this height, collisions are so frequent that quenching occurs before the light can be emitted, but in the mesosphere and above we can collect these photons and make horizon-to-horizon images that reveal much about upper atmospheric phenomena.

Because the atmospheric scale height is relatively small in the mesosphere, the various emission layers are typically less than 10 km thick. Furthermore, the peak emission height is different for different processes. Some of the more important airglow emissions used for upper atmospheric research are summarized in Table 1, which includes emission heights, altitude resolution, exposure time needed for our CCD camera, and other relevant information. Since our imager has five different filter wheel locations, we can, and have, been able to use airglow to determine height variations of geophysical phenomena.

**Table 1.**

| Emission | Wavelength | Height Range | Exposure Time |
|---|---|---|---|
| OH Broadband | Near IR | 87 km | 8 s |
| Greenline | 557.7 nm | 96 km | 90 s |
| Redline | 630.0 nm | 200-300 km | 90 s |
| Sodium | 589.6 nm | 94 km | 90 s |
| Radiative Recombination | 777.4 nm | 250-350 km | 90 s |

In 1993 an article was written by *Carlson and Gardner* [1993] describing the atmospheric science application of an Advanced Electro-Optic System (AEOS), which might evolve at the Air Force Maui Optical Station (AMOS). We sometimes refer below to the AEOS (as discussed in that article) in the context of the CEDAR MAUI-MALT (Mesosphere And Lower Thermosphere) Initiative, which is currently under development. Under this grant we worked within the AFOSR core program in support of AEOS. Our foresight has been rewarded since the project is now officially underway in the joint AFOSR/NSF Maui MLT initiative.

Our research group has long been interested in the possibilities for airglow research in conjunction with a giant lidar on Maui. When this possibility was first raised, internal support amounting to $75K was obtained from the Cornell Theory Center, then a partner with the Maui High Performance Computing Center. Figure 1 shows the camera we purchased and developed for use in upper atmospheric science. As will be described shortly, we have used this camera to great advantage in the intervening years, mostly in Puerto Rico, which is at virtually the same geographic latitude as Hawaii. We also have experience in the Hawaiian sector. Students at all levels have participated: Research Experience for Undergraduates (REU), Master of Engineering students (four M.Eng degrees awarded), and one completed Ph.D. by an NSF Fellow (Francisco Garcia). All of the undergraduates involved were women or minority students, two of the M.Eng. students were female, and Garcia was Hispanic. The P.I. recruited the undergraduates in their freshman year when he was their freshman calculus professor and advisor. The nucleus of the group became the Cornell Airglow Imaging Team. This cycle began again this past fall.

We have maintained excellent communications with the AMOS personnel and, in particular, with Paul Kervin. The P.I. has visited three times, a master's degree student made one trip, and two graduate students have made one and two trips, respectively. This effort was, in fact, funded by AFOSR under a grant entitled "A Proposal to Establish a Preliminary AEOS on Maui for Determining the Source of Wave Disturbances in the Mesosphere".

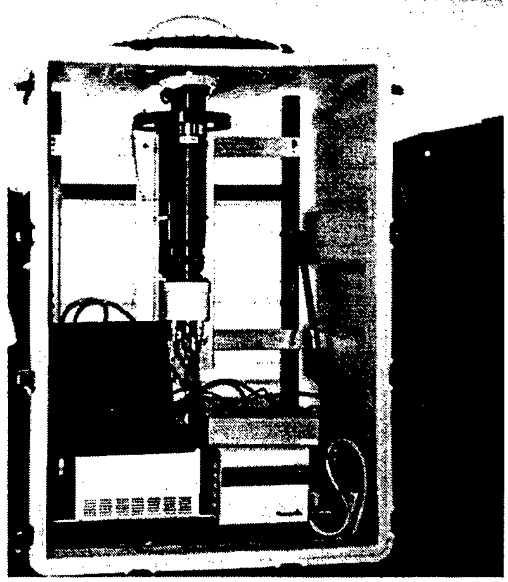

**Figure 1.** The Cornell All-Sky Imager (CASI) in its transportable housing.

The purpose of these visits was to solidify technical relationships with AMOS and to verify our ability to control the camera remotely over the Internet. These tests went remarkably well and we are certain we can operate the camera from Ithaca by using undergraduate students under the direction of a graduate student and the P.I. This is the model used for two years of camera operation in Puerto Rico, which has led to five publications in the refereed literature already. If the project proceeds, the foresight, monetary investment, and technical developments at Cornell, along with the support of the Air Force Office of Scientific Research, will be well justified.

On one of these trips we actually set up the camera, first on Kauai in support of the MF radar, and then on Maui itself. Figure 2 shows examples of images from the thermosphere. These images are quite interesting and of very high quality. Several were used in two papers entitled "Airglow observations of mesoscale, low velocity traveling ionospheric disturbances at mid-latitudes" and "Mesoscale structure of the midlatitude ionosphere during high geomagnetic activity: Airglow and GPS observations" [*Garcia et al.*, 2000a,b], which were part of Francisco Garcia's Ph.D. thesis work [*Garcia*, 1999]. These images were an important component to the paper, since they show that the thermospheric traveling ionospheric disturbances (TID) structures (Figure 2) we found over Puerto Rico were also found over Hawaii. The mesospheric image in Figure 3 has not yet been published, since the background information in the Maui sector was quite limited. This situation will change dramatically with the presence of a giant lidar.

Cornell University recently won a DURIP (Defense University Research Instrumentation Program) award to enhance our Space Weather capability. We will use this money to purchase the narrow field-of-view optics and the GPS dual channel receiver discussion in this proposal.

In addition to our Maui-related airglow activities, we have shown our interests in and abilities to perform high quality work in conjunction with a giant lidar. The P.I. proposed to the National Science Foundation that Cornell join with the University of Illinois and the Starfire Optical Range to carry out a study of long-lived chemiluminescent meteor trails ("Clustering of

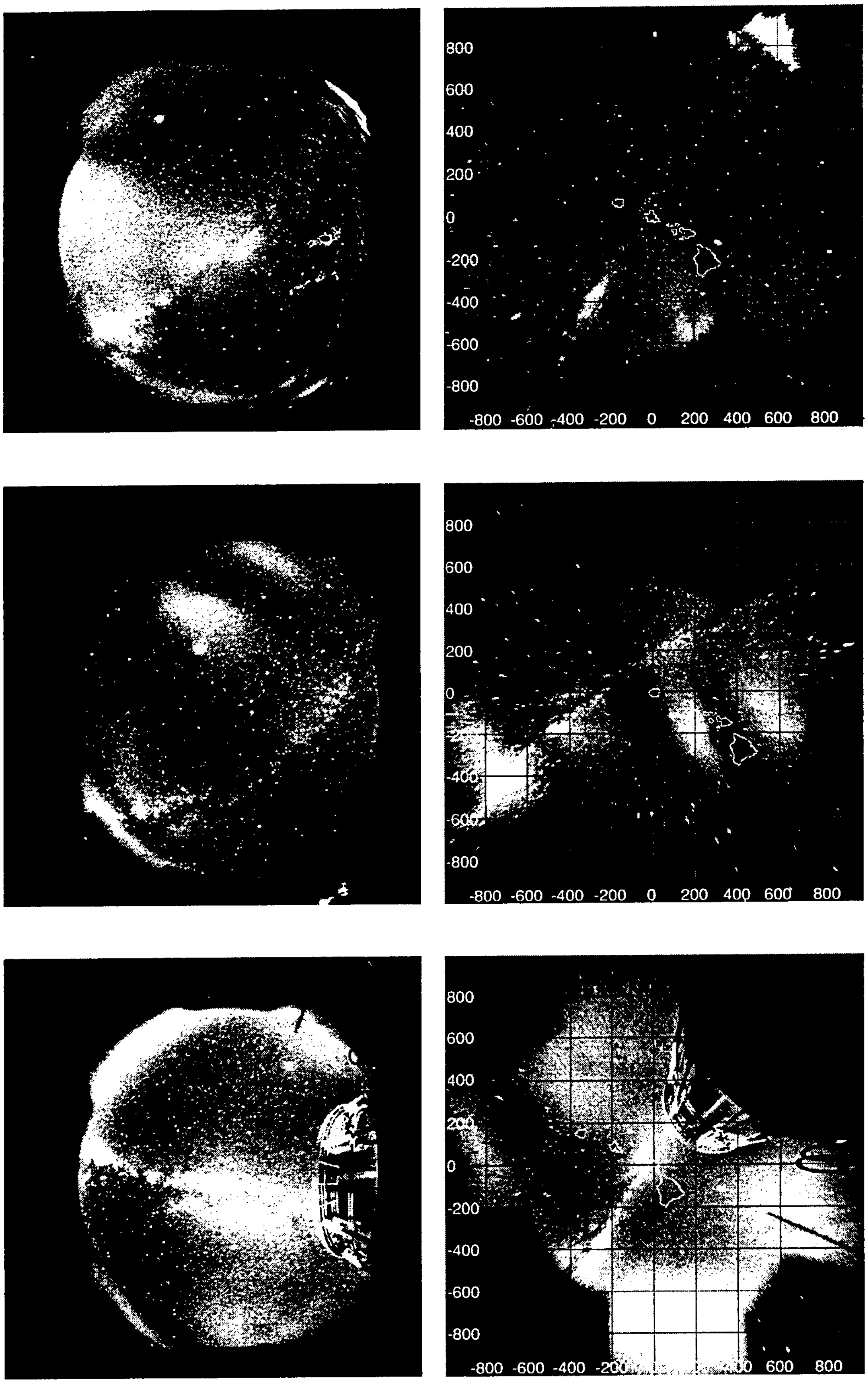


**Figure 2.** A summary of ZTID events from Hawaii using the 630.0 nm filter.

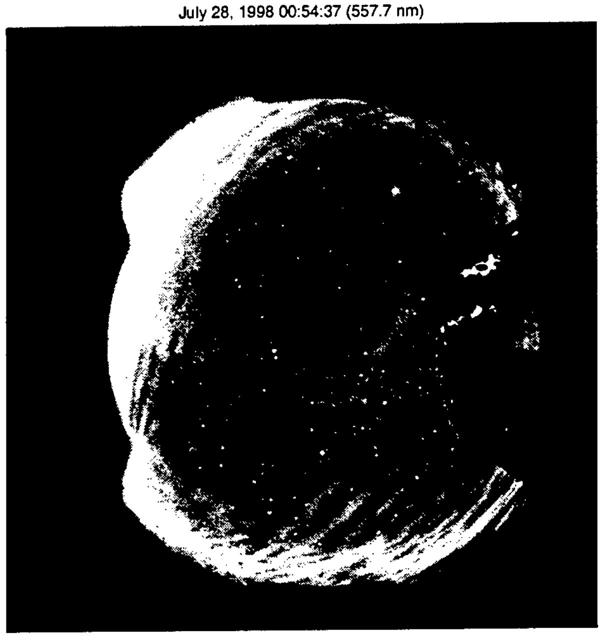

**Figure 3.** Example of a mesospheric image captured with CASI while at Maui.

Instruments for the Study of Long-Duration Meteor Trails"). We organized the project beginning in 1997 and carried out successful experiments in 1998 and 1999. A series of papers was published in *Geophysical Research Letters* [*Chu et al.*, 2000; *Grime et al.*, 2000; *Kelley et al.*, 2000b] and in *Sky and Telescope* [*Drummond et al.*, 2000]. Figure 4 shows the trail called Diamond Ring, captured with a white light camera during the 1998 campaign.

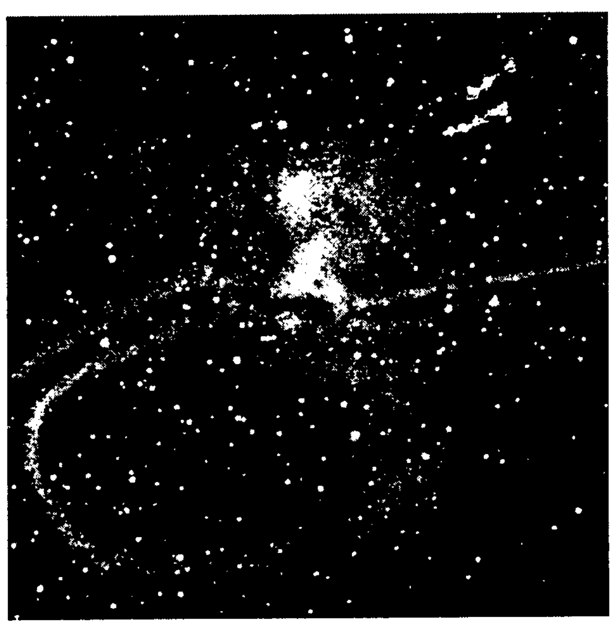

**Figure 4.** The Diamond Ring long-lived meteor trail.

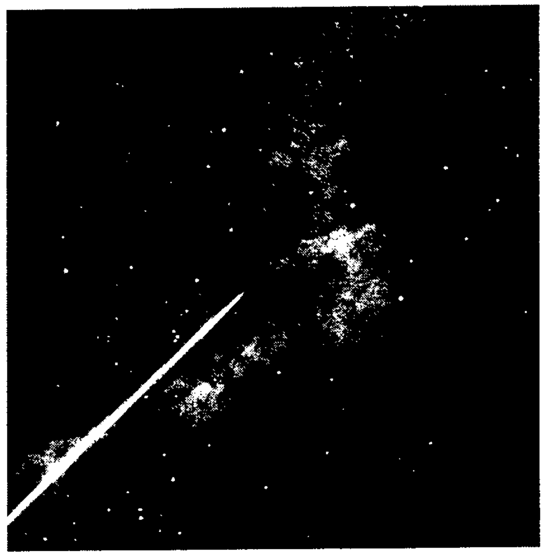

**Figure 5.** The Glowworm trail captured at Starfire Optical Range.

Another spectacular long-lived trail, featured on the cover of *GRL*, is shown in Figure 5, along with the laser beams used to probe the structure. The weaker of the two beams is the sodium laser of the University of Illinois. This trail, dubbed Glowworm, was visible to the naked eye for ten minutes and lasted for over an hour in our all-sky imager data. This data is shown in Figure 6 as the Glowworm drifted across the night sky, stretching and becoming distorted in the mesospheric winds.

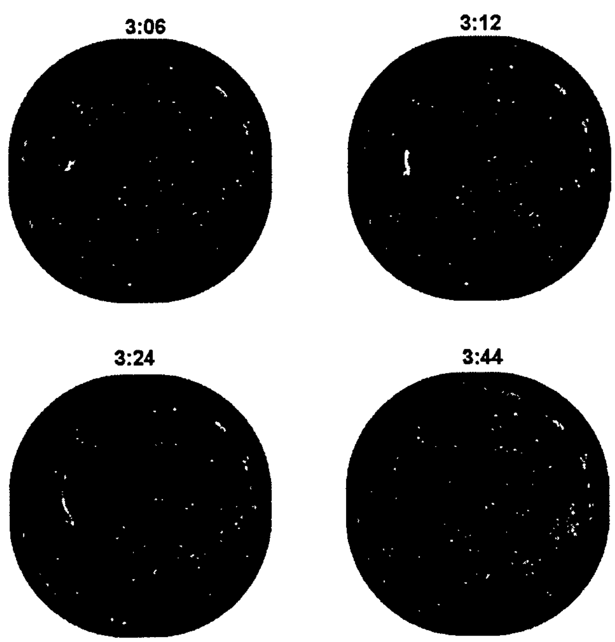


**Figure 6.** All-Sky images showing the Glowworm trail stretching and distorting over time.

Being able to steer a sodium lidar onto the trail has, for the first time, allowed a definitive, quantitative test of the sodium airglow theory for this process since we were able to measure the sodium and the airglow directly. In *Kruschwitz et al.* [2001] a Cornell graduate student reports the results of his chemical-diffusive model for meteor trail evolution. He was able to quantitatively explain the all-sky imager intensities, which ranged from 20-500 Rayleighs in various events. An example of the sodium lidar profile is presented in Figure 7. In this case the lidar beam intersected the trail at two different altitudes and detected sodium density an order of magnitude higher than in the background layer.

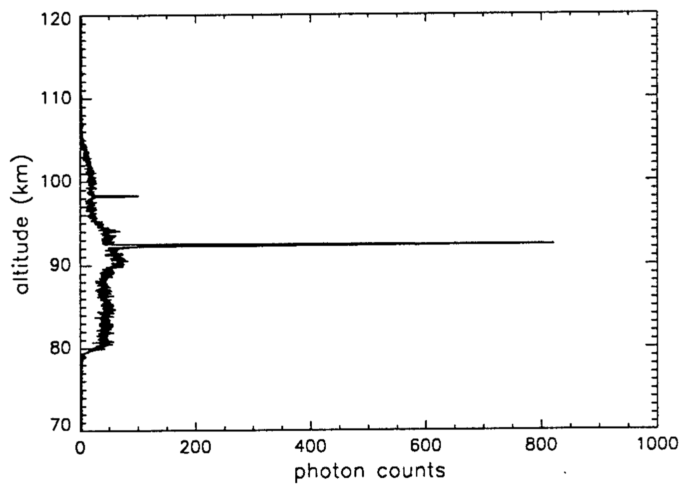


**Figure 7.** Example sodium lidar profile of a meteor trail.

However, these same calculations show equally clearly that the sodium line itself is far too faint to explain the visibility to the naked eye. Most attention has been placed on the trail called the Diamond Ring, shown in Figure 4 as a white light camera image. The photon flux recorded here is over two orders of magnitude higher than the Na model indicates and which our airglow imager measured. By including all the metallic species in typical meteor abundances, making generous assumptions about reaction rates and ignoring absorption in the atmosphere, *Kruschwitz et al.* [2001] have shown that emissions from the vibrational states of $O_2$ approach the photon fluxes measured, but it seems unlikely that all these assumptions are valid.

There are thus many mysteries remaining in these meteor trail studies. Just what is the source of the bright, long-lasting emission? What is the origin of the parallel trail ("hollow cylinder") effect? Why do portions of a trail sometimes exhibit a puffy character (e.g., the diamond part of the Diamond Ring) while sometimes the entire trail has this character (e.g., Figure 5)? We return to these scientific points below. However, we wish to point out that this fascinating work was proposed by the current P.I., who lobbied for and inspired the group effort needed to carry out a very difficult experiment involving a highly transient phenomenon. We pose this leadership aspect as evidence that a Cornell involvement at the Maui facility would be highly productive.

## Summary

Under this grant we have demonstrated that AEOS can be an important new observatory using all-sky imagers and a giant lidar as tools for middle atmospheric studies. Cornell University has invested in the all-sky imager, which has yielded valuable contributions to aeronomy (a total of 5 publications thus far). Three Cornell students have already visited the Maui site, taking airglow data and testing the ability to operate the camera remotely, and several images have been published from that work. In addition, we have designed and carried out a unique set of experiments using the sister facility to the Maui Observatory: the Starfire Optical Range. Working with other upper atmospheric researchers, we have re-opened research into one of nature's most intriguing and least understood phenomena: long-lasting chemiluminescent meteor trails. This experience will be invaluable as the Maui-MLT initiative continues.

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